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Equations for Predicting Earth Penetration by Projectiles: An Update

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Abstract

rizes the equations that were previously published, includes new equations, discusses the applicability of the equations, and presents guidelines for estimating or calculating the empirical constants.

Nomenclature

a — Average acceleration, units of gravity, g
a_p — Peak acceleration, units of gravity, g
A — Penetrator sectional area, in.^{2}
C — Ratio of target width to penetrator diameter
CRH — Caliber radius head, tangent ogive nose shape
d — Penetrator diameter, ft
d_n — Depth at which *n*th layer of a target begins, ft
D — Distance along the penetration path, ft
EPW — Earth penetrating weapon
f_c — Unconfined compressive strength of concrete, psi
f'_c — 28-day unconfined compressive strength, psi
g — One unit of gravity, 32.2 ft/s^2
K_r — Factor to be used in the soil/rock equation when the penetrator weight is <400 lb and the target is rock
K_s — Factor to be used in the soil/rock equation when the penetrator weight is <60 lb and the target is soil
K_1 — Constant for edge effect in concrete
K_2 — Age of concrete, years
L_n — Penetrator nose length, ft
n — The *n*th layer of a layered target
$(\ )_n$ — Implies that the parameter in parentheses is applicable for the *n*th layer only
N — Nose performance coefficient
S — Penetrability constant (often called S-number)
S_{K_n} — Weighted S-number of all target layers above the *n*th layer
S_{R_n} — Estimated penetrability of *n*th layer, based on target material properties, but not considering the depth
SNL — Sandia National Laboratories
T — Thickness of a layer, ft
T_p — Thickness of a layer along the penetration path, ft
TTR — Tonopah Test Range, NV
V — Impact velocity, fps
V_e — Exit velocity, fps
W — Penetrator weight, lb
x — Exponent, defined in text with Eq (16)
Θ — Impact angle, or angle between penetration path and the target surface, degrees

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Introduction

The objectives of this report are (1) to explain which equation should be used for each target type, (2) to show how to estimate or calculate the constants used in the equations, and (3) to discuss some specific penetration problems not covered directly by the equations.

Background

The first SNL penetration equations were published in 1967,[2,3] and these basic equations have not changed, even though the experimental database has increased significantly since that time. However, the early database was predominantly soil penetration, and it was assumed that the same equations applied for all natural earth materials and concrete.

In 1972, the depth prediction capability was improved by developing equations to supplement the penetration equations, making it possible to predict penetration into layered targets with complex penetrator configurations.[4]

In 1974, equations were published to predict penetration into sea ice.[5] About 1980, a small change to these equations was made to better fit the data for lightweight penetrators. This report only includes the equations as currently used.

About 1979, a new equation was developed to better fit the rock and concrete penetration data. The equation was not published formally, even though it is listed in the Appendix of Reference 1. Only recently was it determined that, while the new equation does apply for concrete penetration, the original soil penetration equations are a better fit to rock penetration. The error was not recognized earlier because the equations are almost identical for the higher weight-to-area ratio penetrators used in the late 1970s. The correct equations for rock, soil, and concrete will be discussed in detail in this report.

Penetration Equations

The three basic penetration equations are soil/rock, concrete, and ice and frozen soil. These equations will be discussed by subject, including a discussion of how to estimate the penetrability constant. There will then be separate sections on nose performance coefficient, axial load predictions, and layered targets.